

Hydrodynamics Characteristics of Porous Type Fixed-Oscillating Water Column Wave Energy Converter

Abstract. This study investigates the behavior and performance of Oscillating Water Column (OWC) devices with a modified porous structure. A two-dimensional model of the OWC was simulated using ANSYS FLUENT software. The objective was to assess how changes to the front wall of the fixed OWC, specifically incorporating a porous structure and altering the wall angle, influence wave load and overall performance. The study tested front wall angles of 0 degrees, 30 degrees, and 45 degrees. The results demonstrate that a 0-degree angle with a porous structure is the most effective parameter, reducing pressure by 20.15% and increasing water elevation by 1.84%. These findings can significantly improve OWC device design, boost efficiency, and contribute to the development of more effective and durable renewable energy technologies.

Keywords: Hydrodynamics, Wave Energy Converter, Oscillating Water Column, Porous Structure, Renewable Energy

1 Introduction

Renewable energy is the best alternative which has fewer effects and impacts on the environment. While Malaysia not fully utilized it yet since this country is one of the largest oils and gas producers in the Asia Pacific region. This study highlights the importance of renewable energy as an alternative to fossil fuels, especially in Malaysia. Wave energy is captured from the movement of ocean waves, which are created as the wind blows over the sea's surface, forcing the water to flow in oscillating patterns. Wave Energy Converters (WEC) are used to convert this plentiful and sustainable energy source to electricity. By exploiting the continuous and powerful natural motion of the ocean, wave energy conversion offers a promising method for generating sustainable power. An oscillating water column (OWC) utilizes the oscillation of water inside columns to generate electricity. Currently, the most common type of wave energy currently used is the OWC. The OWC is often built near the shore [1]. The wave propels water into the chamber, and the peaks and valleys create fast-moving air currents with varying directions via the wells turbine, resulting in the production of energy [1]. Study on the water column oscillation and motion was done by Çelik and Abdüsselam [2]. They discovered a critical relative opening height ratio that maximizes fluctuations, independent of the wave parameters used. Additionally, Vyzikas et al. [3] explored various geometries of fixed oscillating water column (OWC) devices, analyzing how different design modifications to the classic OWC

and the U-OWC, initially proposed by Boccotti [4], affect performance. Gaspar et al. [5] performed a numerical analysis comparing the efficiency of two onshore OWC wave energy converters with different chamber wall slopes, finding that the device with inclined walls achieved the highest efficiency, although the other design showed more consistent performance across different wave periods. Venkateswarlu and Karmakar [6] assessed wave dissipation using various porous structures, concluding that a single structure dissipated 91.5% of the energy, while a double structure improved energy dissipation by 12%. Wave Energy Converters (WECs) can be installed along shorelines to harness wave energy. Since energy is conserved, the WEC absorbs, transmits, and reflects the incident wave energy, resulting in a reduction in wave height behind the device. This wave height reduction has additional advantages, particularly as a sustainable alternative to traditional coastal protection methods, especially considering rising water levels due to climate change. Evans and Linton [7] examined this aspect of WECs, while Millar et al. [8] and Mendoza et al. [9] explored the practical application of this mechanism. Mustapa et al. [10] provided a review of prototype devices, and Sorek and Sulisz [11] integrated WECs into breakwater structures using a serpentine wave energy converter. While many studies have focused on OWCs, there has been limited research on the effects of adding porous structures to the front wall. This study aims to investigate the behavior and performance of OWC devices with such modifications. Using a two-dimensional OWC model simulated in ANSYS FLUENT software, the study seeks to determine how changes to the front wall impact wave load and overall performance.

2 Numerical work

The Oscillating Water Column (OWC) model is based on the previous study by Mayon et al. [12]. A two-dimensional model was developed, featuring a numerical wave tank measuring 20.59 m in length and 1.5 m in depth. The OWC is positioned on the seaward side of the chamber's front wall, located 20.0 m from the inlet (Fig. 1). The configuration of the OWC dimensions and the placement of the gauges are crucial for evaluating the OWC's performance and assessing the impact of waves on the front wall.

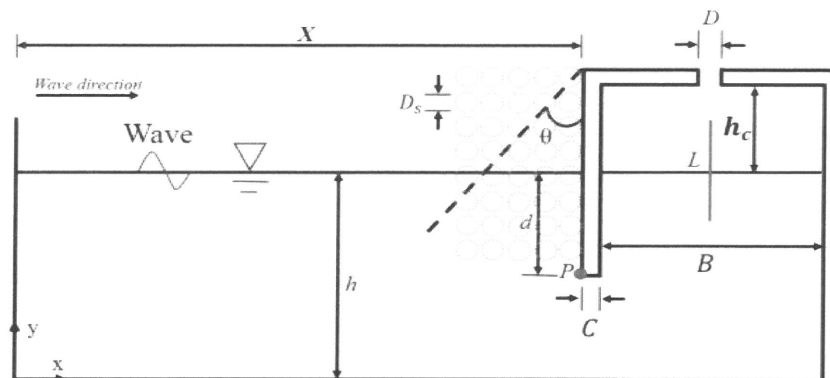


Fig. 1. Numerical domain

Table 1. OWC model parameters

Parameter	Dimension
Distance from inlet to OWC front wall, X	20.00 m
Orifice diameter, D	0.042 m
Diameter of porous, D_s	0.050 m
Angle of front wall from $-y$ axis, θ	0, 30, 45 (degree)
Chamber high from water level, h_c	0.200 m
Still water level, h	0.800 m
Front wall immersion depth, d	0.140 m
Chamber width, B	0.550 m
Front wall thickness, C	0.040 m

The boundary condition setup for OWC is displayed in Fig. 2, where the left side of the geometry is defined as the inlet (blue arrows). The pressure outlet is indicated by the red arrows from the geometry that pointed to the outside. The OWC's bottom and the chamber are both considered as walls.

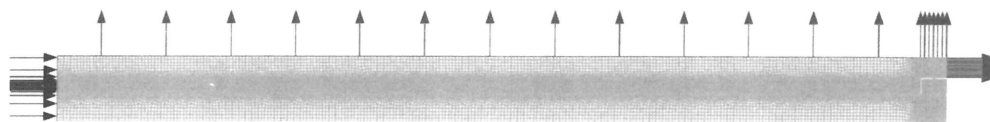


Fig. 2. Boundary Condition Setup for OWC

Figures 3-4 and Table 2 show the mesh used in this study.

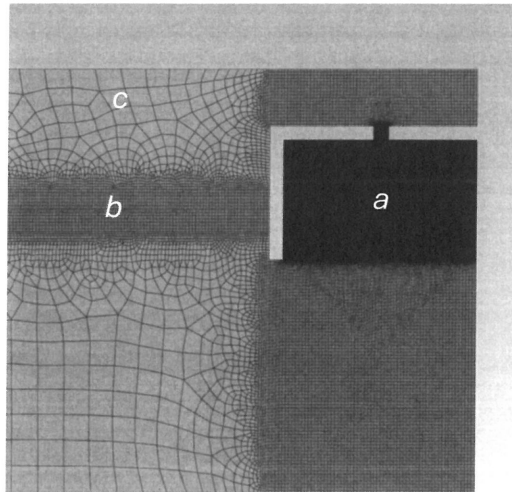


Fig. 3. Mesh for OWC

Table 2. Mesh size

Meshing	Size
Fine, <i>a</i>	0.001 m
Medium, <i>b</i>	0.005 m
Coarse, <i>c</i>	0.075 m

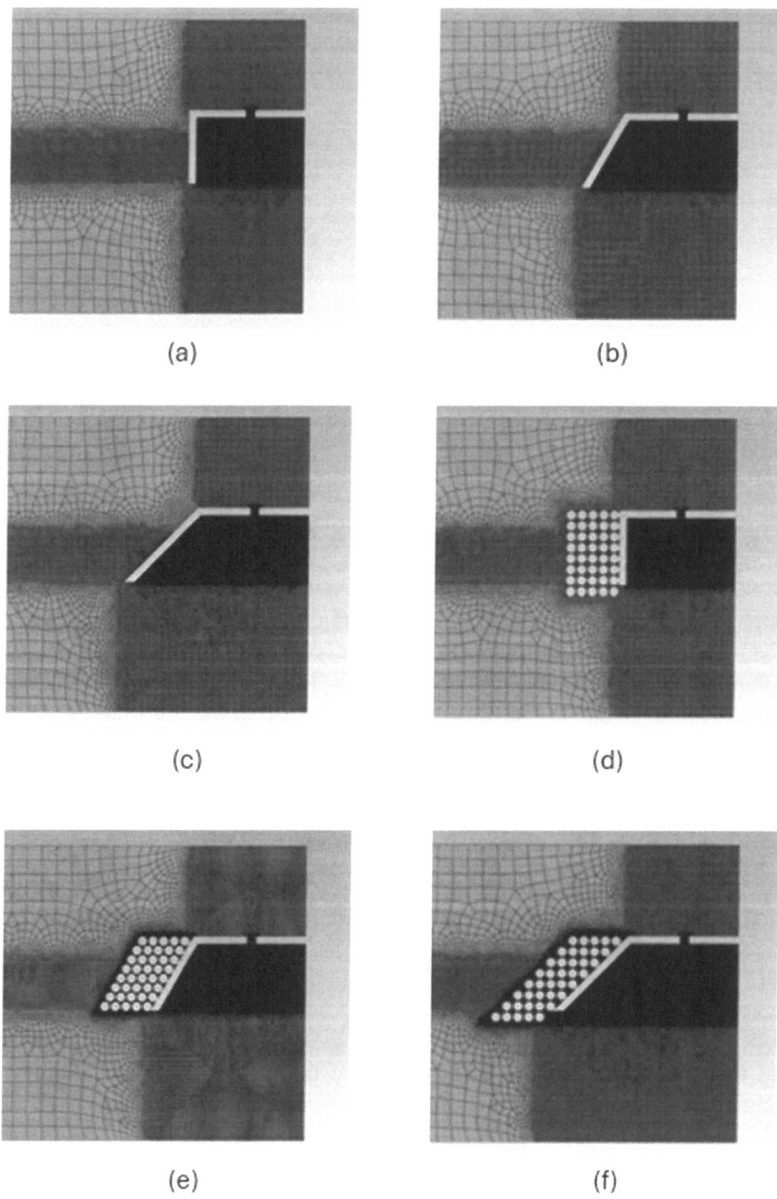


Fig. 4. Mesh for OWC (a) – (c) without porous and (d) – (f) with porous

The Navier-Stokes equation is used to regulate the fluid's advection throughout the simulation. In vector form, the continuity equation is

$$\nabla \cdot \mathbf{U} = 0 \quad (1)$$

and the equation of momentum is

$$\frac{\partial \rho \mathbf{U}}{\partial t} + \nabla \cdot (\rho \mathbf{U} \mathbf{U}) = \nabla \cdot \boldsymbol{\tau} + \rho \mathbf{b} \quad (2)$$

Where

\mathbf{U}	=	Velocity vector of fluid flow
ρ	=	Density of fluid
$\boldsymbol{\tau}$	=	Stress
\mathbf{b}	=	Body force

The expansion of the free surface is modelled using the VOF approach, where a function is assigned to each grid cell inside the domain. This function takes a value of unity for cells totally occupied by water and zero for cells wholly occupied by another fluid. Cells that form the interface between the two fluids have intermediate values. The temporal advection of the free surface is then regulated by the transport equation

$$\frac{\partial a}{\partial t} + u \frac{\partial a}{\partial x} + v \frac{\partial a}{\partial y} = 0$$

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Where u and v are the velocities of the component x and y direction correspondingly.

The hydrodynamic efficiency of an OWC can be determined by examining the relationship between the pneumatic power extracted from the incident waves by the OWC device and the time-averaged energy flow of those waves. This efficiency is expressed as:

$$\xi = \frac{P_0}{P_w w} \quad (4)$$

Where

P_0	=	Pneumatic power
P_w	=	Average energy discharge per unit width
w	=	Width

The air flow rate through the orifice multiplied by the air pressure inside the chamber may be used to calculate the time-averaged product of the pneumatic power absorbed by the OWC as follow:

$$P_0 = \frac{1}{T} \int_t^{t+T} Q(t)p(t)dt \quad (5)$$

Where T = Period of wave
 Q = Air volume through the well turbine
 p = Pressure of air in chamber

The average power per unit width of the incident wave, as determined by linear wave theory, is given by

$$P_w = \frac{1}{2} \rho g A_i^2 C_g \quad (6)$$

Where A_i is the incidence wave amplitude, C_g is the group velocity of the incident wave packet, and g is the gravitational acceleration.

C_g is given by

$$C_g = \frac{c}{2} \left(1 + \frac{2kh}{\sinh(2kh)} \right) \quad (7)$$

Where k is the number of waves, h is the depth of steady and c is the incoming wave velocity given by

$$c = \frac{\omega}{k} \quad (8)$$

Where the angular frequency, ω is calculated by

$$\omega = \sqrt{gk \tanh(kh)} \quad (9)$$

3 Results and discussion

Figure 4 illustrates the pressure difference for all the variation involved in this study. It is found that front wall with varying front wall angles (0 degrees, 30 degrees, and 45 degrees) and structural modifications (with and without porous

structure), the results show by addition of porous structure will reduces the pressure on the OWC front wall.

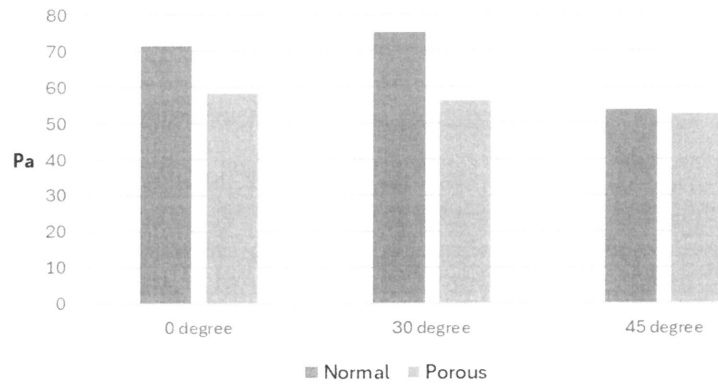


Fig. 4. Pressure difference

Figure 5 illustrates the water level difference for all the modifications of OWC in this study. A level of water elevation inside the OWC chamber is used to interpreted the OWC performance. It is because the water level oscillations inside the chamber are directly proportional to the OWC performance.

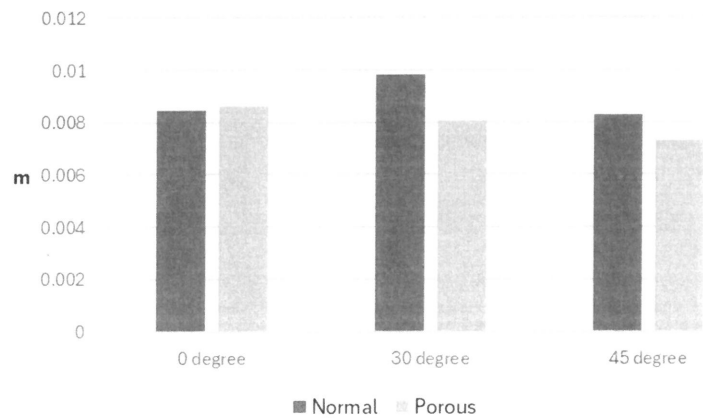


Fig. 5. Water level inside chamber

Figure 6 shows the percentage variation of the water level inside the chamber and the pressure at various angles.

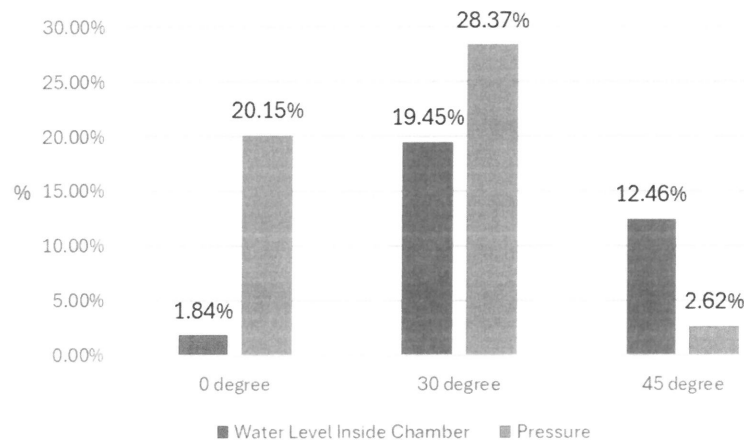


Fig. 6. Percentage difference

The difference was calculated between the normal front wall and the front wall with porous structure. The highest water level difference between normal and porous is OWC at 30-degree of slope, which is at 19.45%, followed by 45-degree with 12.46%, and the lowest is at 0 degrees with 1.84%. The water elevation difference for 30 degree and 45-degree is very significant, but the elevation difference of 0-degree angle of slope is not significant. Even though the elevation difference at 0-degree angle of slope is the lowest, the pressure difference is very significant. At a 30-degree angle of slope, with a percentage difference of 28.37%, the pressure difference between the normal and porous OWCs is most significantly different. This indicates that adding a porous structure effectively reduces the pressure on the OWC front wall. The bigger pressure percentage difference is preferable for best performance. Additionally, keeping small water level percentage differences inside the chamber is crucial to maintaining the performance of the OWC. The water surface inside the chamber is directly proportional to the OWC's performance, meaning that significant fluctuations in water level can negatively impact the device's efficiency.

4 Conclusion

The wave load is higher for the normal OWC front wall compared to the OWC front wall with porous structure. Among the normal OWC front wall, the 30-degree slope of OWC front wall slightly higher than the 0 degree of OWC front wall. The elevation difference of 0-degree angle of slope is not significant which means the addition of porous increase water elevation inside the OWC. The best performance OWC design combines a high-pressure percentage difference with minimal water level percentage differences to ensure both effective pressure management and high overall performance. Therefore, the most practical parameter of OWC is at 0-degree angle of slope (vertical) with porous structure.

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